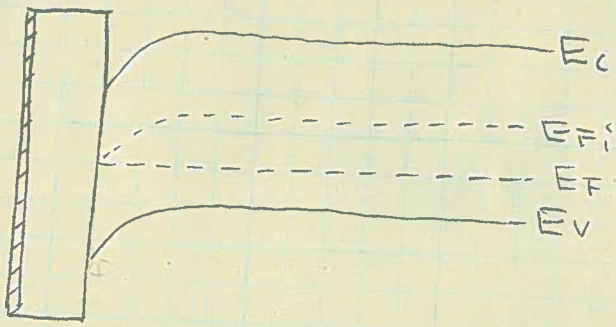
1)



a) $E_F < E_{Fi}$ $\Rightarrow$ substrate p-type $\Rightarrow$ channel will be electron

$\boxed{\text{nMOS}}$

b) To reach Flat band, the potential energy for holes must be lowered $\Rightarrow$ the potential must be lowered

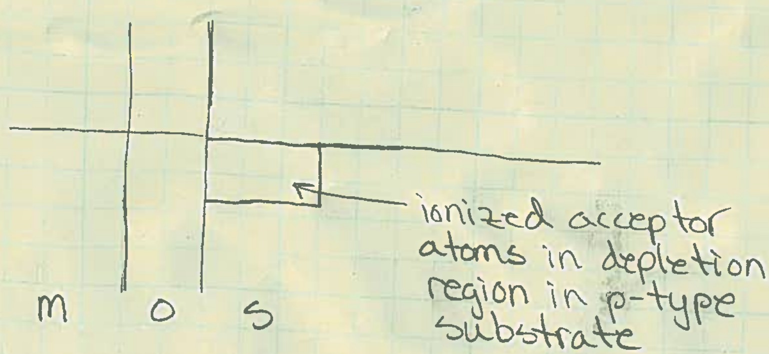
so Flat band polarity is $\boxed{\text{negative}}$

c) To reach threshold, E_{Fi} must drop below E_F and $\phi_s = 2\phi_{Fp}$. The bands need to bend more (opposite of Flat band)

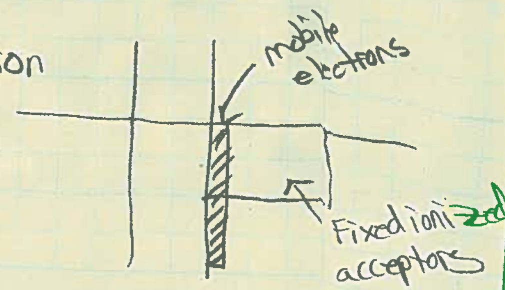
so threshold voltage polarity is $\boxed{\text{positive}}$

d) $\boxed{\text{Enhancement mode}}$ since a voltage must be applied to induce the channel

e)

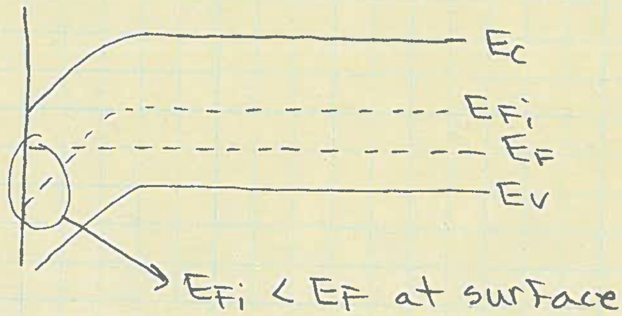


* if we bias the structure to inversion we would have



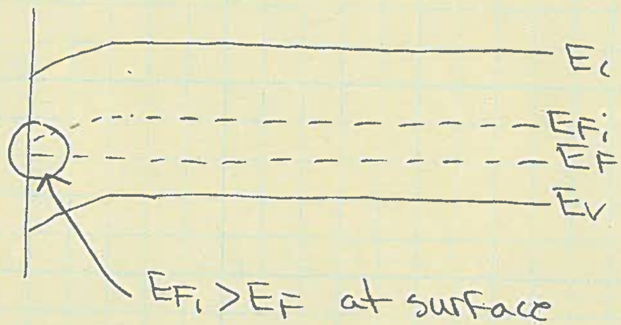
10.1

a) <u>p-type</u> since there is an inversion layer of electrons



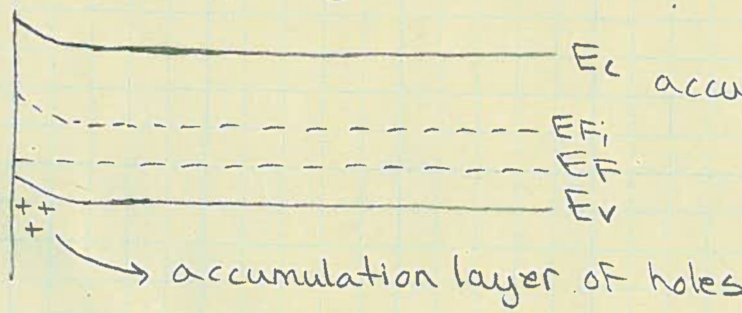
inversion mode

b) <u>p-type</u> since there are ionized negative charges (acceptors)



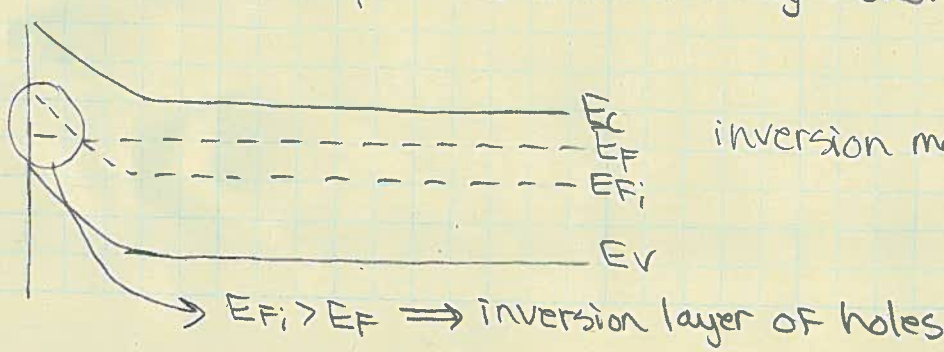
depletion mod

c) <u>p-type</u> since the gate charge is negative and there is an accumulation layer of holes at the surface



accumulation mode

d) <u>n-type</u> since there is a depletion layer of positive charges (i.e. - donors) and a positive inversion layer (holes)



inversion mode

$\boxed{10.12}$ $t_{ox} = 40\text{nm}$ on p-type silicon with $N_a = 5\times10^{15}\text{cm}^{-3}$

$V_{FB} = -0.9V$

Find ϕ_s at threshold inversion point

Find V_T, assuming no charge in oxide

Find x_{dT}

- $\phi_s = 2\phi_{Fp} \longrightarrow \phi_{Fp} = V_T \ln\left(\frac{N_a}{n_i}\right) = 0.0259V \ln\left(\frac{5\times10^{15}\text{cm}^{-3}}{1.5\times10^{10}\text{cm}^{-3}}\right)$

$= 0.3294V$

so $\phi_s = 2(0.3294V) = \boxed{0.6588V}$

- For $V_{TN} = \frac{|Q'_{SD}(max)|}{C_{ox}} + V_{FB} + 2\phi_{Fp}$

need $|Q'_{SD}(max)| = eN_a x_{dT}$

$$x_{dT} = \left(\frac{4\epsilon_s\phi_{Fp}}{eN_a}\right)^{1/2} = \left(\frac{4(11.7)(8.85\times10^{-14}\text{F/cm})(0.3294V)}{(1.6\times10^{-19}c)(5\times10^{15}\text{cm}^{-3})}\right)^{1/2}$$

$$\boxed{= 4.13\times10^{-5}\text{cm}}$$

$|Q'_{SD}(max)| = (1.6\times10^{-19}c)(5\times10^{15}\text{cm}^{-3})(4.13\times10^{-5}\text{cm}) = 3.304\times10^{-8}\text{C/cm}^2$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.85\times10^{-14}\text{F/cm})}{(40\times10^{-7}\text{cm})} = 8.629\times10^{-8}\text{F/cm}^2$

$V_{TN} = \frac{3.304\times10^{-8}\text{C/cm}^2}{8.629\times10^{-8}\text{F/cm}^2} - 0.9V + 0.6588V \boxed{= 0.142V}$

$\boxed{10.16}$ n^+ polysilicon gate $-SiO_2-$ silicon MOS capacitor

$t_{ox} = 18\,nm$, $N_a = 10^{15}\,cm^{-3}$, $Q_{ss}' = 6 \times 10^{10}\,cm^{-2}$

$\hookrightarrow$ p-substrate $\rightarrow$ n-channel

a) Find V_{FB} ?

$$V_{FB} = \phi_{ms} - \frac{Q_{ss}'}{C_{ox}}.$$

From Fig. 10.16 : $\phi_{ms} \approx -1.0\,V$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.85 \times 10^{-14}\,F/cm)}{18 \times 10^{-7}\,cm} = 1.918 \times 10^{-7}\,F/cm^2$$

$$\text{so } V_{FB} = -1.0\,V - \frac{(6 \times 10^{10}\,cm^{-2})(1.6 \times 10^{-19}\,C)}{1.918 \times 10^{-7}\,F/cm}$$

$$\boxed{V_{FB} = -1.05\,V}$$

b) Find V_T ?

$$V_{TN} = \frac{|Q_{SD}'(max)|}{C_{ox}} + V_{FB} + 2\phi_{Fp}$$

$$|Q_{SD}'(max)| = eN_a x_{dT} \qquad x_{dT} = \left(\frac{4\epsilon_s \phi_{Fp}}{eN_a}\right)^{1/2}$$

$$\phi_{Fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.0259\,V \ln\left(\frac{10^{15}\,cm^{-3}}{1.5 \times 10^{10}\,cm^{-3}}\right) = 0.288\,V$$

$$\text{so } x_{dT} = \left(\frac{4(11.7)(8.85 \times 10^{-14}\,F/cm)(0.288\,V)}{(1.6 \times 10^{-19}\,C)(10^{15}\,cm^{-3})}\right)^{1/2} = 8.634 \times 10^{-5}\,cm$$

$$\text{so } |Q_{SD}'(max)| = (1.6 \times 10^{-19}\,C)(10^{15}\,cm^{-3})(8.634 \times 10^{-5}\,cm) = 1.38 \times 10^{-8}\,C/cm^2$$

$$\text{so } V_{TN} = \frac{1.38 \times 10^{-8}\,C/cm^2}{1.918 \times 10^{-7}\,F/cm^2} - 1.05\,V + 2(0.288\,V) \boxed{= -0.402\,V}$$

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$\boxed{10.35}$ n-channel FET

$k_n' = 0.6\ mA/V^2$

$V_T = 0.8V$

$I_D = 1mA$ when $V_{GS} = 1.4V$, $V_{SB} = 0$, $V_{DS} = 4V$

a) What is W/L?

For saturation $V_{DS} > V_{GS} - V_T = 1.4V - 0.8V = 0.6V$

so $V_{DS} = 4V > 0.6V$

$\Rightarrow$ in saturation region

so $I_D = \frac{W \mu_n C_{ox}}{2L}(V_{GS} - V_T)^2 = \frac{k_n'}{2}\left(\frac{W}{L}\right)(V_{GS} - V_T)^2$

$$\Rightarrow \frac{W}{L} = \frac{2I_D}{k_n'(V_{GS} - V_T)^2} = \frac{2(1mA)}{(0.6mA/V^2)(1.4V - 0.8V)^2}$$

$$\boxed{W/L = 9.26}$$

b) I_D? when $V_{GS} = 1.85V$, $V_{SB} = 0$, $V_{DS} = 6V$

$V_{GS} - V_T = 1.85V - 0.8V = 1.05V < V_{DS}$

$\Rightarrow$ saturation region

$$I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)(V_{GS} - V_T)^2 = \frac{0.6mA/V^2}{2}(9.26)(1.05V)^2$$

$$\boxed{I_D = 3.06\ mA}$$

c) I_D? when $V_{GS} = 1.2V$, $V_{SB} = 0$, and $V_{DS} = 0.15V$

since $V_{GS} - V_T = 0.4V > V_{DS} \Rightarrow$ linear region

$$I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]$$

$$= \frac{0.6mA/V^2}{2}(9.26)\left[2(0.4V)(0.15V) - (0.15V)^2\right] \boxed{= 0.271\ mA}$$

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